Hue Correlate Stability using a Gaussian versus Rectangular Object-Colour Atlas

Hamidreza MIRZAEI, Brian FUNT
School of Computing Science, Simon Fraser University

ABSTRACT

The perceptual correlate to hue and the stability of its representation in the coordinates of Logvinenko's illumination-invariant object-colour atlas (Logvinenko, 2009) are investigated. Logvinenko's object-colour atlas represents the colours of objects in terms of special rectangular reflectance functions defined by 3-parameters, α (chromatic purity), δ (spectral bandwidth) and λ (central wavelength) describing the rectangular reflectance to which it is metameric. These parameters were shown to be approximate perceptual correlates in terms of chroma, whiteness/blackness, and hue, respectively. When the illumination changes, the mapping of object colours to the rectangular atlas coordinates is subject to a phenomenon referred to as colour stimulus shift. The perceptual correlates shift as well. The problem of colour stimulus shift is exacerbated by the fact that the atlas is based on rectangular functions. This paper explores the benefits of using the Gaussian parameterization of the object-colour atlas (Logvinenko, 2012) in terms of its robustness to colour stimulus shift and in terms of how well it maps to the perceptual correlate of hue.

1. INTRODUCTION

This paper compares the Gaussian parameterization (Logvinenko, 2012) of Logvinenko's object-colour atlas (Logvinenko, 2009) to its underlying 'rectangular' form in terms of the effects of colour stimulus shift and how well its central/peak wavelength parameter correlates with hue. In terms of background, it is important first to consider the relevant aspects of traditional colour atlases, Logvinenko's rectangular atlas, and his Gaussian parameterization of the rectangular atlas.

Commonly used colour spaces in the Colour Science literature, such as CIE 1931 and its derivatives, are more appropriate for representing self-luminous than reflecting objects. In the case of reflecting objects, such spaces may work well for a fixed, standard illuminant, but can lead to unsatisfactory results under different illuminants. CIELAB and related spaces include an adjustment for the illumination based on the colour stimulus (XYZ) of the perfect reflector via a von Kries scaling, but von Kries scaling can be subject to very large errors (Logvinenko, Funt, Mirzaei, & Tokunaga, 2013). The Munsell and NCS colour atlases have the advantage that they are based on sets of reflecting papers, but they also are not illuminant invariant because the perceptual distance between the papers is likely to change with a change in the illumination. For some strictly positive illuminants, in fact, it is possible that two papers will become metameric.

To address these problems, Logvinenko introduced an illumination-invariant colour atlas to represent the colour of objects (Logvinenko, 2009). He defines an object-colour atlas in terms of a special set of non-metameric, optimal spectral reflectance functions. For any sensor set and strictly positive illuminant spectral power distribution, any colour stimulus maps to a unique member of the object-colour atlas, in particular, to its metameric member under the given illuminant. The elements of Logvinenko's rectangular object-colour atlas are rectangular reflectance functions that are defined as a mixture of flat grey (constant reflectance of 0.5) and a rectangular optimal reflectance component taking only values 0 or 1, with at most 2 transitions between 0 and 1. Given λ_1 and λ_2 as transition wavelengths, it is also possible to express the optimal reflectance functions by their central wavelength λ and a spectral bandwidth δ.

The 3-parameters of the atlas, α (chromatic purity), δ (spectral bandwidth) and λ (central wavelength) were shown (Logvinenko, 2009) to be rough perceptual correlates of chroma, whiteness/blackness, and hue, respectively. When the illumination changes, the mapping of object colours to the rectangular atlas coordinates—and hence of the perceptual correlates too—is subject to a phenomenon referred to as colour stimulus shift. Although the object-colour atlas itself is illumination invariant, this does not mean that an object's coordinate specification within the atlas will not change with the illumination. This is simply a consequence of the fact that two objects that are metameric under one illuminant may no longer be metameric under a different illuminant. In the case of the rectangular object colour atlas, this means that the coordinates of the object may change as the object becomes metameric to a different one of the atlas's rectangular functions.

The effect of colour stimulus shift is exacerbated by the fact that, by their very nature, the rectangular functions include two very sudden jumps, one up and the other down. In a subsequent paper, Logvinenko (Logvinenko, 2013) suggests a "wraparound" Gaussian parameterization (k scaling, σ standard deviation, μ central wavelength) of the rectangular colour atlas. Since Gaussians are smooth they may mitigate the effects of colour stimulus shift.

The Gaussian parameterization uses a three-parameter wraparound Gaussian function for representing reflectance spectra. The wraparound Gaussians are defined as follows.

Let $\Lambda = \lambda_{\max} - \lambda_{\min}$ and $\theta = 1/\sigma^2$. When $\mu \le (\lambda_{\max} + \mu_{\min})/2$ then: (1) for $\lambda_{\min} \le \lambda \le \mu + \Lambda/2$, $g(\lambda; k, \theta, \mu) = k\exp[-\theta(\lambda - \mu)^2]$; and (2) for $\mu + \Lambda/2 \le \lambda \le \lambda_{\max}$, $g(\lambda; k, \theta, \mu) = k\exp[-\theta(\lambda - \mu - \Lambda)^2]$. When $\mu \ge (\lambda_{\max} + \mu_{\min})/2$ then: (1) for $\lambda_{\min} \le \lambda \le \mu - \Lambda/2$, $g(\lambda; k, \theta, \mu) = k\exp[-\theta(\lambda - \mu + \Lambda)^2]$; and (2) for $\mu - \Lambda/2 \le \lambda \le \lambda_{\max}$, $g(\lambda; k, \theta, \mu) = k\exp[-\theta(\lambda - \mu)^2]$.

Then, for $0 \le k \le 1$, $\lambda_{\min} \le \mu \le \lambda_{\max}$ and positive θ, we have a wraparound Gaussian reflectance function. In this representation, the roles of μ and σ are analogous to those of central wavelength λ and spectral bandwidth δ defined in the Logvinenko's original αδλ coordinate system. We will refer to the triple $k\sigma\mu$ as the $k\sigma\mu$ coordinates, where σ stands for standard deviation, and μ stands for the peak wavelength, and k for the scaling.

In what follows, we explore the benefits of using the Gaussian parameterization of the object-colour atlas in comparison to the original rectangular atlas in terms of its robustness to colour stimulus shift and in terms of how well it maps to the perceptual correlate of hue.

2. HUE CORRELATE

As shown in Figure 1, Munsell hue correlates better with the Gaussian atlas coordinate μ than with the rectangular atlas coordinate λ. The combination of greater resistance to colour stimulus shift combined with better correlation with Munsell hue argues in favour of using the Gaussian parameterizaton of the colour atlas for a hue correlate.

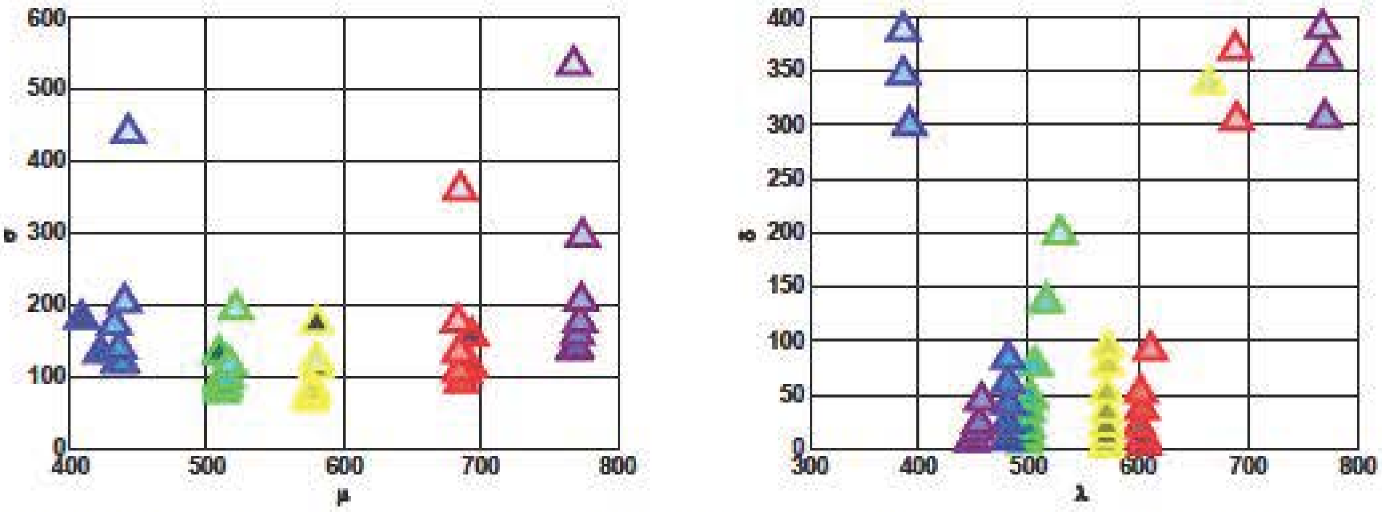

Figure 1: Colour descriptors of the Munsell papers of maximal chroma from five pages (10B, 10G, 10Y, 10R, and 10PB) of the Munsell Book of Color. Each paper is plotted as a point with Cartesian coordinates: μ and σ (Gaussian) in the left panel; λ and δ (rectangular) in the right panel. The boundary of each triangle is coloured based on its Munsell hue. The vertical alignment of the papers of the same Munsell hue in the left panel indicates a strong correlation between hue and the peak wavelength parameter μ. The right panel shows some correlation between λ and hue, but to a much lesser extent than for μ and hue.

3. COLOUR STIMULUS SHIFT IN A GAUSSIAN VERSUS RECTANGULAR OBJECT-COLOUR ATLAS

Metamer mismatching means that an object colour can move from one class of metamerism to another when the illumination changes. Since an object's coordinates in the object-colour atlas are based on the atlas's reflectance to which it is metameric, its atlas coordinates may alter when the illumination changes. Such a shift is called the illuminant-induced color stimulus shift (Logvinenko, 2009). The apparent magnitude of the colour stimulus shift may depend on whether it is described in terms of the coordinates of the rectangular object-colour atlas versus its Gaussian parameterization.

To determine the relative stability of μ versus λ coordinates under a change in illuminant, we synthesize the XYZ tristimulus values of 1600 Munsell chips under two illuminants (e.g., D65 and F11) using the colour matching functions and then determine the corresponding μ and λ coordinates. Figure 2 plots the corresponding μ and λ parameters superimposed. The figure shows that the μ hue descriptor stays relatively the same regardless of whether the illuminant is F11 or D65. In the figure, the λ coordinates deviate from the diagonal more than their μ counterparts. To the extent that μ is more stable than λ it could potentially be a superior hue correlate. Based on circular statistics, differences of the central/peak wavelengths in nanometers for μ are 4.7 (mean), 2.8 (median), and 114 (maximum) versus for λ for which they are 9.2 (mean), 4.9 (median), and 120 (maximum). The relative stability of μ in comparison to λ has been found to hold for other illuminant pairs as well. For 20 Munsell papers illuminated by 15 different illumination combinations (see Fig. 3 of Logvinenko & Tokunaga (2011)) the wavelength difference in nanometers is significantly less: mean 18 versus 35, and median 25 versus 45.

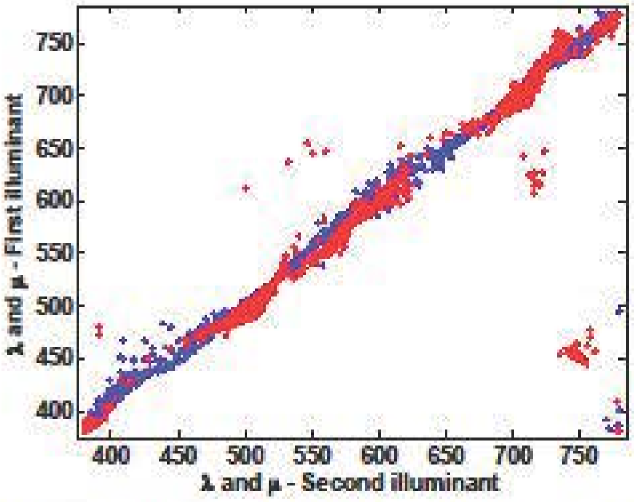

Figure 2. Comparison of μ (blue) and λ (red) coordinates calculated under D65 and F11. The ordinate are values for D65 and the abscissa are values for F11. Note that due to the wraparound property of the Gaussians and the rectangular reflectances, the λ and μ values near 380nm are in fact close to those at 780nm, so some of the apparent outliers are in fact not outliers.

4. CONCLUSIONS

In the Gaussian parameterization of Logvinenko's object-colour atlas, the peak wavelength μ of the wraparound Gaussian is shown to correlate well with Munsell hue. It correlates better than the central wavelength λ of the rectangular functions from the original colour atlas. Both μ and λ have the advantage over other hue descriptors in that they are components of the coordinates in an illumination-invariant object-colour atlas. Even so, they are subject to the limits imposed by metamer mismatching, which mean that there can still be colour-stimulus shift. Tests show that the degree of colour-stimulus shift is smaller, in practice, for the Gaussian-based hue descriptor than its rectangular counterpart. Combined with the fact that it correlates better with Munsell hue, the Gaussian-based descriptor is likely to be the better choice as a perceptual correlate of hue.

REFERENCES

Logvinenko, A., 2009. An object-color space. *JOV*, 9(11, Article 5), 1-23.

Logvinenko, A., 2013. Object-colour manifold. *IJCV*, 101(1), 143-160.

Logvinenko, A., and R. Tokunaga, 2011. Colour constancy as measured by least dissimilar matching. *Seeing and Perceiving*, 24(5), 407-452.

Logvinenko, A., B. Funt, H. Mirzaei and R. Tokunaga, 2013. Metamer Mismatching's Impact on Colour Constancy. Under review.

Address: Professor Brian Funt, School of Computing Science, Simon Fraser University,
8888 University Drive, Burnaby, British Columbia, Canada V5A 1S6.
E-mails: funt@sfu.ca, hmirzaei@sfu.ca.